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Agronomic and economic benefits of primary and secondary micronutrients in selected fertilizer applications in rice production in Uganda

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Abstract. Two sets of trials were conducted during 2020 and 2021 in Amuru sub-county, Amuru District with the following objectives: Set 1 – to determine which secondary and micronutrient limit rice yield; and Set 2 – to compare the yield and economic benefits of applying rice specific NPK blend to application of NP as DAP and urea. Each farmer had one replicate, with other farmers serving as replications. There were 10 to 15 farmers per trial per season. There was a significant increase at p < 5% in grain yield of 2.6 t ha^{-1} above the control (1.7 t ha^{-1}) with application of a combination of NP with K, Ca, Zn, B and Cu. Omitting either K, Ca, Zn, B or Cu on average resulted in a significant decrease in grain yield (0.74 t ha^{-1} vs. 4.3 t ha^{-1} - when all the nutrients were applied) at p < 5% level. The net benefit of adding K, Ca, Zn, B and Cu to NP was Uganda Shillings 1,602,000/=, 739,000/=, 834,315/=, 906,189/=, and 1,057,603/=, respectively. There was a significant increase in rice yield of 1.5 t ha^{-1} with a benefit to cost ratio of 2 with application of (125 kg DAP + 125 kg urea) ha^{-1} compared with 2.3 t ha^{-1} and a B/C of 2.3 with application of (250 kg rice specific NPK + 125 kg urea) ha^{-1}, confirming that rice specific fertilizers are better than application of NP only. The study confirms that micronutrients limit crop yield in Uganda and should be included in balanced fertilizer formulations. Rice specific fertilizers are better than urea and DAP fertilizers recommended by MAAIF.

Keywords: Fertilizer blends, Rice Specific NPK, net benefits, nutrient omission trials.

Introduction

Rice is an important crop for the smallholder farmers in Uganda for food, nutrition and income security. Like other crops, rice yield per unit area of production at farmers field are low. The main contributing factors are poor inherent soil fertility, particularly N and P deficiencies (Bekunda et al., 1997), exacerbated by soil fertility depletion and nutrient mining (Wortmann and Kaizzi, 1998; Vlek, 1993; Sanchez et al., 1997; Lynam et al., 1998), and other biotic and abiotic factors. Land degradation and soil fertility or nutrient depletion are considered as the major threats to food security and natural resource conservation in Sub Saharan Africa (SSA) (Sanchez, 2002). It is now agreeable that fertilizers are essential to counteract declining soil fertility and improve agricultural productivity. Unfortunately social and economic factors do not favour the use of inorganic fertilizers by the smallholder farmers in SSA. Inorganic fertilizers cost two to six times as much as in Europe (Sanchez, 2002) mainly due to transport costs, marketing inefficiencies, and other charges. Other factors underlying the low fertilizer use in Sub Saharan Africa (SSA) is the relatively high nutrient to grain price ratio which causes unfavourable benefit to cost ratios. Resource-poor farmers need large returns on the small investments that they can make, often requiring benefit to cost returns of 2 within a six to twelve month period (Wortmann and Ssali, 2001). Low fertilizer use efficiency can result from inappropriate fertilizer products, inappropriate fertilizer use practices, limited fertilizer knowledge by all stakeholders and poor recommendations that need to account for the cash constraints and risks affecting resource-poor farmers. Greater use of inorganic fertilizer, supplemented with soil and water conservation and organic nutrient supplementation, is central to realizing the productivity and yield increases required to override the current situation.

Crop response to application of N, P and K fertilizers is still below the breeders' yield potential of most crops, indicating the need for more fertilizer products including blends and probably lime to add to the common ones on the market. One of the major constraints of the fertilizer market in Uganda and in SSA in general is the narrow range of fertilizer products which are dominated by urea, DAP, SA, TSP, SSP, MOP, SOP, CAN, and NPK of different formulations with 17:17:17 for sugarcane the most common, 25:5:5+5S for tea, and 25:25:25 for Oil Palm, etc. However, due to land degradation there is need for balanced fertilizer formulation on the market for farmers to achieve expected financial benefit from fertilizer use. There is evidence that use of crop and site/soil specific fertilizer blends that incorporate secondary and micro-nutrients can boost African crop yields by 25% (Kihara et al. 2017). However, mixed response by finger millet to application of Mg+S+Zn+B varied from negative to 29% (Kaizzi et al., 2017) indicating that either Mg, S, Zn and B or their combination are limiting crop yields in Uganda. The same applies to other countries in SSA. Application of balanced fertilizer blends will result in increased soil productivity and crop yields hence food, nutrition and income security for the smallholder farmers, vulnerable groups and others living below the poverty line. Fertilizer blends with secondary and trace elements will not only increase yield but also balance crop nutrition and address deficiency of these nutrients where they are limiting crop production. However during the previous studies the secondary and trace elements were applied as a mixture. There is need to conduct nutrient omission trials to establish which secondary and micro nutrients limit crop production. This information is required by fertilizer blending facilities in the country and SSA to produce balanced fertilizer blends of the right formulation. However, the economics of using fertilizer blends should be determined, since the profitability of fertilizer use decreases with application of more nutrients. The objectives of the study were to; establish which particular secondary (Ca, K) and trace elements (Zn, B, Cu) are limiting rice yield; determine which nutrients are economically justified in a formulation; and assess yield and overall economic returns of rice specific blends compared to use of a combination of urea, and DAP.

Methodology

Site Characteristics and Experimental Design

Two sets of trials were conducted namely (i) Nutrient omission trials, and (ii) comparing the agronomic and economic benefit of rice specific fertilizer blend with application of urea, diammonium phosphate (DAP) and muriate of potash (MOP) were conducted in Amuru Sub-

County, Amuru District located in Northern Moist Farmlands (Wortmann and Eledu, 1999) during 2020 and 2021. The trials had a single set of the same treatments per farm; farms within district were treated as replications, and there were 15 farms (replications) per district. The treatments were randomized per farm. Plot size was 3 m x 4.2 m.

Surface soil samples for the 0- to 20-cm depth consisting of 10 cores per site-season were collected with hand probes before planting and fertilizer application to determine soil pH, soil organic matter (SOM) (Walkley and Black, 1934), and available P and exchangeable K measured in a single Mehlich-3 extract and buffered at pH 2.5 (Mehlich, 1984)). Soil texture was determined by the hydrometer method (Okalebo et al., 2002).

The treatment structure of the nutrient omission trials is presented in Table 1. All treatments received a blanket application of 90 kg N ha^{-1} and 20 kg P ha^{-1}. The all-nutrient treatment received all nutrients i.e., potassium (K), calcium (Ca), zinc (Zn), boron (B) and copper (Cu) at rates indicated in Table 1. In the other treatment, one nutrient was omitted as indicated.

Table 1. Treatment structure of the nutrient omission trials (kg ha^{-1})

	Treatment$^{\$}$	N	P	K	Ca	Zn	B	Cu
1	N P K Ca Zn B Cu (ALL)	90	20	30	15	2.5	0.5	0.38
2	N P Ca Zn B Cu (- K)	90	20		15	2.5	0.5	0.38
3	N P K Zn B Cu (- Ca)	90	20	30		2.5	0.5	0.38
4	Control	0	0	0	0	0	0	0
5	N P K Ca B Cu (- Zn)	90	20	30	15		0.5	0.38
6	N P K Ca Zn Cu (- B)	90	20	30	15	2.5		0.38
7	N P K Ca Zn B (- Cu)	0	0	0	0	0	0	

The fertilizers applied were urea, triple super phosphate, and muriate of potash for N, P and K, respectively. Fertilizer N and K were applied with 20% at planting, 40% at tillering and 40% at panicle initiation. The fertilizers were broadcast at planting and incorporated. The side dress application of N and K was applied to the side of the row and covered. Calcium, zinc, boron and copper were applied as calcium sulphate, zinc sulphate, boron and copper sulphate, respectively. The micro nutrient fertilizers were mixed with sand and applied since the amount were small.

In the study comparing the yield and economic benefit of applying 250 kg/ha of rice specific NPK blend plus 125 kg urea to application of (125 kg DAP + 125 kg urea)/ha. The fertilizer NPK and DAP were applied at planting. Urea was applied 20% at planting, 40% at tillering and 40% at panicle initiation.

The treatments were -randomized per farm considered a replicate. Plot size was 20 m by 20 m. The trials had a single set of the same treatments per farm; farms within the district were treated as replications, and there were 6 to 10 farms (replications) per district.

Crop Management and Data Collected

Site preparation included ox ploughing at 15 to 20 cm depth. Seeding rates were selected to ensure final plant populations of 50 plants m^{-2}, with spacing of 20 cm by 20 cm. In-season weed control was by weeding with hand hoes twice or thrice depending on weed intensity. During the season, chloropyrifos 5% (DursbanTM) was applied for control of the stem borer complex and the African rice gall midge (Orseolia oryzivora Harris & Gagné (Diptera: Cecidomyiidae).

Data Analysis

The analyses were done by site-season, clusters of on-farm trials, and combined across site-seasons and clusters of on-farm trials using Statistix 10 (Analytical Software, Tallahassee, FL) with sites and replications as random variables and nutrient rates as fixed variables. Differences and relationships were considered significant at $P \leq 0.05$.

(i) The economic benefit of a particular nutrient (Y) is obtained by subtracting the cost of nutrient ha^{-1} (b) from the value of lost yield (c) due to due to omission of that particular nutrient.
Where b = (cost of nutrient (Ug Shs. per kg) * application rate (kg ha^{-1}))
c = Yield loss (kg ha^{-1}) * farmgate price of maize
Y = c – b
If
Y is positive, it means that it is economically viable to include that nutrient in the fertilizer formulation.

If
Y is negative, it means that it is economically viable to include that nutrient in the fertilizer formulation.
The price of fertilizers used in the economic analysis were Uganda shilling 200,000/= for urea and Triple Super Phosphate (TSP); and 149,000/= for Muriate of Potash (MOP) per 50-kg bag. The price of 50-kg bag of calcium sulphate, 25-kg bag of zinc sulphate, 25-kg bag of boron and 25-kg bag of copper sulphate was Uganda shillings 125,000/=, 185,000/=, 222,000/= and 375,000/=, respectively. Considering the nutrient content in the fertilizer products, the cost of calcium, zinc, boron and copper was Uganda Shillings 10,730/=, 20,274/=, 77,622/= and 58,939/=, respectively. The farmgate price of paddy used was Uganda shillings 1500/= per kg.

(ii) To compare rice specific blend with application of urea and DAP
The price of fertilizers used in the economic analysis are Uganda shillings 180,000/= and 200,000/= for rice specific NPK blend and urea, respectively. The farmgate price of paddy rice used was Uganda shillings 1500/= per kg. Opportunity cost for resource-poor people with small amounts of money is often 100% of the actual value due to other high priority uses and investment opportunities (CIMMYT, 1988). Therefore, benefit: cost ratios (BC) of two or greater is required for an investment to be attractive to such farmers.

Results

Site characteristics

Soil texture classes included sandy clay loam, sandy loam, clay loam, loam, and clay (Table 2). Sand content ranged from 35 to 80%. The SOM range was in the range 1 to 6.4% with 83% of the farmers' fields had SOM below the critical level of 3% for soils of Uganda. The soil pH was in the range 4.7 to 6.7 with the majority of the fields (96.7%) with soil pH above the critical value of 5.2. Mehlich-3 P was below the critical level of 25 ppm, implying that phosphorus is limiting crop production. Available potassium was in the range 68 to 545 ppm with only 27% of the fields having values below 135 ppm, which indicates low supply of K from the soil. Available calcium was in the range 550 to 2310 ppm with 95% of the fields having values above the critical value, implying that the soils will supply sufficient calcium to growing crops. Available magnesium was in the range 1200 to 1094 ppm with all fields having values above the critical value, implying that the soils will supply sufficient magnesium to growing crops.

Table 2. Range and median values of selected soil physico-chemical properties

Soil parameter Number of samples = 41	Range	Median	Fields low levels$ (%)
pH (1 soil:2.5 water)	4.7 – 6.7	5.8	3.3
OM (%)	1.0 – 6.4	2.2	83
Available P (mg kg^{-1})	0.3 – 12.6	1.4	100
Extractable K (mg kg^{-1})	68 - 545	246	27
Extractable Ca (mg kg^{-1})	608 - 2310	1500	0
Extractable Mg (mg kg^{-1})	120 - 1094	389	0

$Percentage of field with low levels of a given nutrient or parameter. These fields require improving the levels of that nutrient or soil parameter.

Paddy Rice yield response to omission of a particular nutrient, value of lost yield and the economic benefit of applying a particular nutrient

Results presented in Table 3 indicate that omitting any given nutrient resulted into a significant reduction in rice paddy yield compared to the treatment which received all nutrients. As expected, the yield loss due to omitting a given nutrient results into economic loss. This implies that the different nutrients are economically viable to be included in the fertilizer formulation. There is economic benefit to application of potassium, calcium, zinc, boron and copper because the value of lost production/yield exceeds the cost of a given nutrient.

Table 3. Average rice yield in response to application all nutrients and with omission of a given nutrient

Treatment	Yield	Yield loss	Rate	price kg nutrient	Cost of Fert/ha	Value of lost production / yield	Benefit
	kg/ha				Uganda Shillings		
ALL	4.19	0					
MinusK	3.05	1.14	30	5,960	178,800	1,140,000	961,200
MinusCa	3.59	0.60	15	10,730	160,950	600,000	439,050
MinusZn	3.6	0.59	2.5	20,274	50,685	590,000	539,315
MinusB	3.56	0.63	0.5	77,622	38,811	630,000	591,189
MinusCu	3.47	0.72	0.38	58,939	22,397	720,000	697,603

Paddy rice yield response to application of Grainpulse rice specific blend compared to application of urea and DAP (referred to as MAAIF recommendation)

Results presented in Figure 1 show a significant increase in paddy rice yield of 2.2 and by 1.3 t ha^{-1}, respectively with application of grain pulse rice specific NPK fertilizers and with application of DAP and urea (MAAIF) recommendations, respectively over the two seasons combined. Yield from the treatment which did not receive fertilizers referred to as the control was 1.91 t ha^{-1}. The superiority of crop specific fertilizer blends, above the MAAIF recommendation is attributed to potassium, secondary and trace elements in the blended fertilizers in addition to N and P.

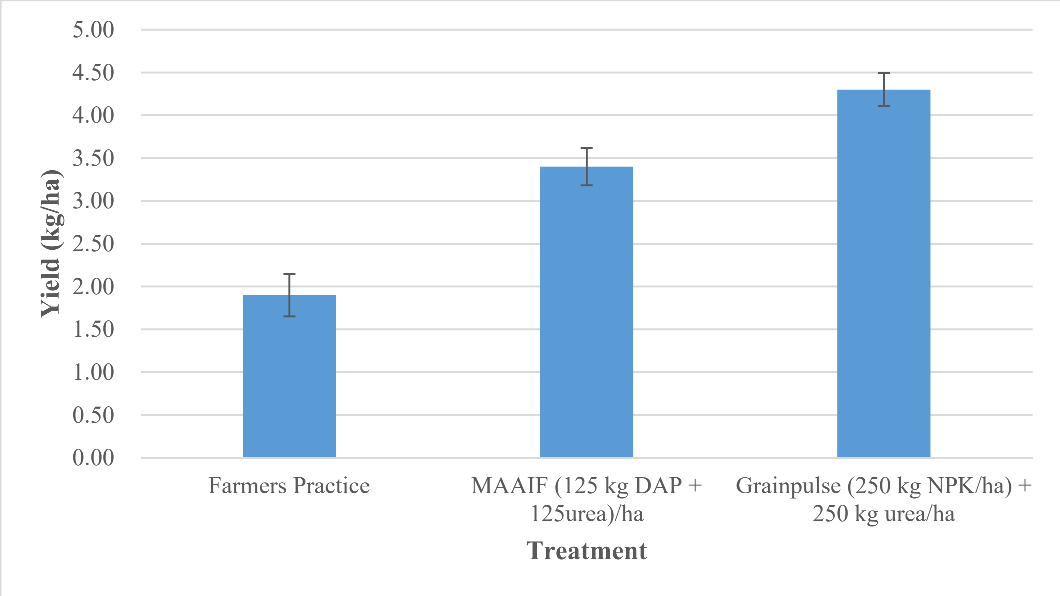

Figure 1. Rice yield in response to Grainpluse Rice Specific Fertilizer, DAP and urea during 2020 and 2021

Economic benefit of rice specific fertilizers over application of urea and DAP (MAAIF recommendation)

It is observed from the Table 4 that application of rice specific fertilizers resulted in a benefit to cost ratio of 1.34 compared to 1.38 for MAAIF recommendation. Though the B/C is above 1, the recommended minimum B/C ratio is 2 for technology adoption by farmers. Resource-poor farmers need large returns on the small investments that they can make, often requiring benefit to cost returns of 2 within a six-to-twelve-month period. This implies that fertilizer application is not economically attractive to farmers at the current high fertilizer prices.

Table 4. Benefit cost analysis of application of Grainpulse rice specific fertilizers compared to MAAIF recommendation

Treatment	Yield (kg/ha)	Gross field benefit (UgX/ha)	Total cost that varies	Net Benefit	B/C ratio
MAAIF (125 kg DAP + 125urea)/ha	3,370	4,044,000	2,926,100	1,117,900	1.38
GP (250 kg NPK/ha) + 250 kg urea/ha	4,320	5,184,000	3,854,600	1,329,400	1.34

Discussion

The majority of the fields (83%) have low soil organic matter content, yet it is one of the most important parameters influencing soil fertility in Uganda as a source of nutrients, increasing water holding capacity, source of food for the macro- and meso- fauna, and source of carbon for the micro fauna. Due to its importance on soil chemical, biological and physical fertility, farmers should make effort to improve its content through use of organic and inorganic sources. Use of external sources of nutrients will increase yield, leaving behind significant quantities of residues not only for animal fodder but also those which remain in the field will be a source of food for macro-, meso- and micro-fauna. The final decomposition product of organic residues is soil organic matter. However, this is a long-time strategy. Available phosphorus is a major constraint because most of the soils have Mehlich-3 P levels below the critical level of 25 ppm, implying that phosphorus is limiting crop production. This implies that farmers will have to use organic and inorganic P sources to prevent crops from suffering. Though available potassium, and magnesium indicate that the soil will supply enough nutrients, their application through the use of organic and inorganic sources is advisable to replace nutrients removed as constituents of crop harvests, and those lost through soil erosion. This is important not only to increase yield but also for long-term sustainability.

Crop response to applied nutrients is the most valuable indicator of the importance of low soil nutrient availability. The significant reduction in paddy yield with omission of a particular nutrient implies that nutrient is limiting rice yield, a confirmation of declining soil fertility because previously it was only N and P which were known to be limiting nutrients in Uganda (Bekunda et al, 1997; Bekunda et al., 2007). This agrees with finding by Wortmann et al., 2019, Kaizzi et al., 2017 and a review by Kihara et al. (2017). The decline in soil fertility is attributed to poor soil fertility management through non-use of organic and inorganic sources of nutrients, and through soil erosion. Yet use of organic and inorganic sources of nutrients and soil erosion control are recommended soil fertility management practices in Uganda. The significant paddy yield in response to application of Graipulse rice specific fertilizers compared with applying (125 kg DAP and 125 kg urea) ha^{-1} recommended by MAAIF implies that the former is better which is attributed to potassium in the blended fertilizers in addition to N and P confirming the results from nutrient omission trials that potassium is now limiting rice production like other crops production in Uganda.

Economic analysis indicates economic benefit are obtained with application of these nutrients; hence they should be included in the fertilizer formulation for rice because farmers recover their cost since the value of yield increase with their application exceed their cost. The benefit to cost ratio of Grainpulse rice specific fertilizer and MAAIF recommendation though above 1, they are still below the value of 2 which is a recommended benefit: cost ratio of any technology to be profitable to smallholder farmers according to FAO is 2.0. The observed benefit to cost ratio is at those values despite the significant increase in yield in response to application of fertilizers because of the high cost of fertilizers which reduce the observed yield benefit. This make fertilizer application not economically attractive to smallholder farmers at the current high fertilizer prices because they are mainly after high returns on their investment but also due to the high opportunity cost of their money.

Agronomic analysis confirmed that potassium, calcium, zinc, boron and copper limit rice yield in Uganda, indicating that the soils have degraded further because previously it was N and P which were known to limit crop production in Uganda. It is economical to include these elements in the blended fertilizer formulation for rice, which can be done in a phased approach starting with potassium, followed by copper, boron, zinc then calcium.

Graipulse rice specific fertilizers are better than applying DAP and urea only this is attributed to potassium in the blended fertilizers in addition to N and P, confirming the results from nutrient omission trials that potassium is now limiting crop production in Uganda. The benefit to cost ratio of Grainpulse rice specific fertilizer (1.34) and of application of urea and DAP fertilizers (1.38) only though indicate profitability they are still below the recommended value of 2 for any technology to be profitable to smallholder farmers according to FAO. This is attributed to the high cost of fertilizer and low farmgate price of rice resulting in high cost of nutrient to farmgate price of produce (C: P) ratio.

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